MUSCLE- AND NERVE-ACTION.*

BY C. HEITZMANN, M.D.,

NEW YORK.

UP to our day peculiar views were upheld by histologists, with regard to muscle- and nerve-tissue. L. Beale, in 1860, announced these tissues to be formed material, placing them on about the same level with the basis-substance of the connective tissue, though observation plainly shows that the tissues of muscle and nerve are the most active and energetic in the animal organism. We must necessarily consider them as formations of living matter, provided in a marked manner with all the properties of life.

The first accurate observer of the structure of tissues, Theodore Schwann, considered the striped muscle-fibers as composed of numerous delicate beaded fibrillæ, so that each muscle-fiber might be regarded as a primitive muscle-bundle. With Schwann the splitting of the muscle-fiber into longitudinal fibrillæ was the essential point. Later, Bowman demonstrated that under the influence of certain acids, the dilute nitric, lactic acid, stomachic juice, and others, the muscle-fiber would split transversely into discs, each of which was composed of a number of prismatic pieces, the sarcous elements. Preservation in alcohol, according to the last-named observer, would favor the splitting of the muscle-fiber into longitudinal fibrillæ; but neither the transverse nor the longitudinal divisions exactly correspond to the structure of a muscle-fiber, which we must consider as being composed of two substances, a contractile and a non-contractile substance, the splitting of which in one main direction would merely be the result of reagents. Bowman's views were adopted by E. Brücke. This observer claimed that the rows of sarcous elements within a muscle-fiber are by no means unchangeable formations, but their grouping during life greatly varies, in at least nine different situations, whereas we see the sarcous elements under the microscope in a certain group that preserved its shape in the moment of the death of the muscle-fiber. Brücke's views must be considered correct so far as they prove that in the muscle-fiber there are but two principal substances, a contractile and a non-contractile, the former being represented by the rows of sarcous elements (double refracting substance), the latter by an interstitial substance (simple refracting substance). All later assertions concerning the structure of the muscle-fiber we regard as unnecessary complications of this, comparatively simple, structure, their number having lately increased to such an extent that some physiologists mention at least, six different substances as existing within the muscle-fiber.

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In 1873, I proved that all the sarcous elements, whatever their mutual arrangement, are connected with each other by means of delicate fibrillæ, both in longitudinal and transverse directions. Thus, the muscle-fiber is built up after the plan of a single "protoplasmic" body, which we know to be traversed, at a certain stage of development, by a delicate reticulum. The reticulum I demonstrated to be living matter, and, accordingly, the sarcous elements and their connecting threads are formations of the living or contractile matter in a regular reticular arrangement; whereas the fluid or semi-fluid substance, filling the meshes of the reticulum, is the non-contractile or non-living portion of the "protoplasm" in general, and also of the muscle-fiber. Contractility, the attribute of life, will be preserved in the muscle so long as the sarcous elements remain inter-connected, regardless of their mutual arrangement. Not infrequently we are unable to discern in fresh muscle-fiber any structure at all, the sarcous elements becoming visible only after a certain period. Again, temporarily the sarcous elements may be irregularly scattered through the fiber, or portions of it, and, nevertheless, the power of contractility is fully preserved, as proved by the application of the interrupted electric current. It is not correct, to assert that the muscle-fiber presents a certain constant and regular arrangement of the sarcous elements, and to say, for instance, that a broad row of sarcous elements is followed by a narrow or granular row, or two narrow rows are arranged between two broad rows, and so on; for the most common feature under the microscope is, should the sarcous elements be discernible at all, that broad rows of sarcous elements are separated from each other by light interstices, varying in diameter, at pretty regular intervals. The filamentous connections between the sarcous elements likewise vary in their aspect at different times, those running transversely from a sarcous element to all its neighbors being plainly visible only exceptionally, on account of the extremely narrow interstices, between the sarcous elements in the transverse direction. The longitudinal filaments may pass from the middle of a sarcous element to that of the nearest upper and lower one, giving each formation a fusiform appearance. Not infrequently, however, the longitudinal filaments pass from the periphery of one sarcous element to that of its neighbors, there being an apparent double connection of each of these bodies with the adjacent upper and lower one.

Such a double connection would also admit of a different interpretation, viz., that a solid sarcous element was followed upward and downward by a hollow vacuole, filled with liquid, the walls of the vacuole being visible only at both edges, though really encircling the vacuole. In this conception of the structure the solid, prismatic pieces of the contractile substance were alternately followed by spaces, filled with liquid, and bordered by extremely thin layers of living matter.

Whatever the arrangement of the sarcous elements be, the contraction of the fiber will exhibit exactly the same features as are visible in a contracted portion of a lump of protoplasm, an amœba, for instance. The granules or prisms become thickened, more bulky, the connecting threads become shortened, as the interstices are rendered narrower, and consequently the meshes between the sarcous elements decrease in size. The result of such a contraction consists in a shortening and broadening of the whole muscle-fiber. On the contrary, in the state of expansion the prisms become narrower, slightly elongated, the filaments are expanded, and the meshes enlarged. The extended muscle-fiber will accordingly be thinned and elongated. The process of contraction and extension performs its function in different portions of the body of a single "protoplasmic" lump, while in the muscle-tissue groups of fibers are in contraction, other groups, simultaneously, in extension. Upon this division of labor is obviously based the antagonism of the muscle-groups.

The nerve-tissue, according to our present views, must be largely constructed of living matter in all its central, conducting, and peripheral portions, for it is endowed with a high degree of activity, the so-called "vital force." The true central portion of the nervous system is the gray substance, and in this, as many good observers maintain, only the ganglionic elements, the so-called "ganglion-cells," are the active parts. Within these elements the living matter is arranged in the form of a reticulum, first described by Frommann. The same arrangement is visible all through the gray substance, as I first observed in 1874, and is now fully acknowledged by S. Stricker. The broadest axis-cylinders likewise exhibit a delicate reticular structure; whereas, in the narrow ones light and dark fields are discernible only, the former being possibly accumulations of a liquid, *i. e.*, vacuoles. The fine staxis-cylinders, with our best modern microscopes, do not exhibit any structural differences. In the terminal axis-fibrillæ a beaded, rosary-like appearance is the most common feature, which would allow the conclusion that the reticulum is arranged in its simplest form, that of threads.

In looking over the reticulum throughout the nervous system, we are at once struck by the delicacy of the granules—*i. e.*, the points of intersection of the net-work. In comparison with the muscle-tissue the difference is apparent. Here we have bulky, prismatic points of intersection, the sarcous elements; in the nerve-tissue, delicate granular thickenings only. The contraction of the former, in all evidence, will be slow but powerful, resulting in intense mechanical work; in the latter the contraction will be quick, starting in the ganglionic elements and running to the periphery, or in the opposite direction, from the periphery to the centre. The nerve-action is possibly based upon this rapid contraction of the living matter, and the isolated conduction thereof through the connective tissue of the body, the general carrier of nerves. We are at a loss, however, to explain the conduction of nervous impulse through the finest axis-cylinders and axis-fibrillæ.

All physiologists admit that the centres of nervous activity are the ganglionic elements scattered throughout the gray substance. We realize that a contraction of the reticulum of the living matter, starting at a peripheral portion of the body, will run a centripetal course and result in a sensitive or sensory perception. A contraction starting, on the contrary, in a central ganglionic element and running to the periphery, to the motor apparatus, will be a motor impulse and result in motion. Both the centres of sensibility and motility are located in the gray substance in separate centres, though both centres are again inter-connected. From this point of view we hardly need speak of motor and sensitive nerves, for both exhibit the same structure and, as experiments directly prove, may be fit for either motor or sensitive conduction, according to the centripetal or centrifugal direction of the impulse. It will suffice, then, to speak of sensitive and motor centres, or ganglionic elements, which must necessarily be inter-connected within the gray substance.

Far more divergent views are expressed regarding the physiological dignity of the gray substance that surrounds the ganglionic elements. Meynert and Stricker consider this substance as inert, as connective tissue, without the property of nervous action. Ewald and Kühne take this substance for keratoid or horny material, as they failed in obtaining its digestion by tripsine. The large number of globular and oblong nuclei scattered throughout the gray substance would certainly indicate a high degree of vitality of the gray substance and disprove the theory of its being neuroglia or connective tissue. Stricker admits that under certain conditions ganglionic elements may originate from the nuclei of the gray substance. Spina has demonstrated that in thin sections of this substance, removed from freshly killed animals and transferred to the slide with an indifferent liquid, such as blood-serum, a very active motion is visible in the reticulum, while the medullated nerve-fibers, which according to Exner traverse the gray substance in large numbers, remain unchanged. Observation of the process of encephalitis under the microscope directly shows that inflammatory corpuscles originate from the points of intersection of the net-work of this substance, the same as from the ganglionic elements. All this goes to prove an active participation of the gray substance in the function of the nerve-centres. The question, whether we have to deal here with connective tissue or nerve tissue proper, probably will never be satisfactorily answered, for we have no means to accurately determine the properties of either in their transitional forms, especially if basis-substance, the characteristic feature of connective tissue, be entirely absent, as in the gray substance.

The terminations of sensitive and vasomotor nerve-fibers are accurately studied in different portions and organs of the body. We know that the fibers take their course to all epithelial layers covering the surface of the body, lining the cavities, and producing glandular prolongations. We meet with such fibers in surprisingly large numbers in the cement-substance between the epithelia, exclusive, of course, of horny epithelia which are destitute of the properties of life. We see the nerve-fibers in direct communication with the transverse fibrillæ of living matter, the so-called thorns, which inter-connect all neighboring epithelia. We realize that the nerve-impulse can be directly transmitted from the connecting filaments of the epithelia into the interior of the latter, which likewise exhibit a reticular or filamentous structure. Should the contraction of this reticulum start in the interior of the epithelia, we understand its transmission to the nerve-fibres, running between the epithelia, to be the perception of sensation by centripetal conduction. Whether or not axis-fibrillæ ever enter the interior of the epithelia, is a much vexed but undecided question. For connective-tissue corpuscles such a penetration of axis-fibrillæ cannot be doubted, as W. Hassloch has, in my laboratory, plainly demonstrated such a penetration and pervasion of axis-fibrillæ into and through the cornea-corpuscles. He traced the ultimate fibrillæ even into the basis-substance. Both here and in the cornea-corpuscles the axis-fibrillæ are in uninterrupted connection with the reticulum of the living matter. Similar observations were made in the connective tissue of the capsules of articulations by Nicoladoni.

Far more difficulty was experienced in the explanation of the action of motor nerve-fibers, which, as we know since Doyère's discovery, do not penetrate the muscle-fibers, but terminate on their surface in the shape of a branching plexus, or a plate, or a hill. Most of the histologists agree that this termination occurs beneath the sarcolemma-sheath. Brücke announced, over twenty years ago, that the rows of the sarcous elements may be compared to rows of soldiers, who, according to the command of the colonel, the motor nerve, may at any time change their mutual arrangement. Kühne has considered the muscle-tissue as a direct prolongation or expansion of the nerves. But how could these conceptions be admitted so long as there was no connection either supposed or demonstrated between the nerves and the sarcous elements? If every muscle-fiber is provided with but one or two nerve-terminations in its whole length, how could we explain the transmission of the motor impulse into the fiber, which certainly contracts all through its length with a certain degree of rapidity?

Until quite recently, on the muscles of different animals, three varieties of terminal apparatus were described—viz., the terminal nerve-hill in the arthropoda; the nerve-tuft in amphibia, and the terminal nerve-plate in reptiles, birds, and mammals. Kühne especially lay stress upon the difference between terminal tufts and plates. Two years ago, however, L. Bremer demonstrated that in the frog and lizard a variety of transitional forms occurs between the main types of Kühne. Bremer found sometimes two medullated nerves entering the same terminal apparatus, also non-medullated nerve-fibers, either connected with the medullated ones in a plexiform arrangement, or producing umbellated terminal apparatus—such as have been mentioned previously by Tschierew. According to Kühne, in the motor plates of all higher animals the surface is occupied by a broad-fused layer of medullated nerves. Gerlach first described a delicate fibrous reticulum within the hill, the presence of which was doubted by later observers. But from what I have seen, it would seem there could be no doubt as to the direct union of the axis-cylinders with the delicate net-work in the depths of the motor hill, which network is again in connection, by means of delicate threads, with the neighboring sarcous elements. How the branching plexiform, medullated, and the non-medullated, probably sensitive, nerves join the contractile matter of the muscle, is as yet unknown.

Thus a direct connection is established between the muscle and the motor nerve, and, as all sarcous elements within the muscle-fiber are again inter-connected, a continuity of the living matter is established from the motor centre, the motor ganglionic elements, to the muscle-fiber, —that is to say, its sarcous elements. We are now prepared to understand how the impulse of the colonel—the motor nerve—is directly transmitted to the regiment of soldiers—the rows of the sarcous elements. If we are pleased to accept Kühne's view, that the muscle is an expansion of the nerve, there is no obstacle, inasmuch as both the muscle and the nerve are formations of living matter.

The ultimate question is: What causes the motion of the living matter? The forms of motion dependent on the contractility or irritability of living matter, are controlled by complex laws, which we term the "will" and the "spontaneity" of living matter. According to M. Foster, the term "automatic motion" is preferable to "spontaneous," inasmuch as it does not necessarily carry with it the idea of irregularity, and bears no reference to a "will." This automatic motion is characteristic of any living organism, the simplest amœba, as well as the most complicated mammal. To call the cause of this motion "vital force," is a mere transcription of the facts, but no explanation. I. Fletcher, in 1835, was the first who absolutely abandoned the idea that the material elements of an organism require the addition of an immaterial or spiritual essence, substance, or power, general or local, whose presence is the efficient cause of life, and who arrived at the conclusion that it is only in virtue of a specially living matter, universally diffused and intimately interwoven with its texture, that any tissue or part possesses vitality. Among all tissues, the muscles and nerves are richest in living matter, hence, the most active. The power that makes these tissues move and contract lacks definition.